increases rapidly with field strength and therefore it becomes possible to obtain emission at temperatures as low as room temperature if the field be increased sufficiently. This is a crude explanation of a phenomenon of which a more accurate discussion would require a great deal more space.

The relation derived by Fowler and Nordheim is of the form

$$I = \frac{CF^2}{\sqrt{\phi_0}} \epsilon^{-r\phi_0^{3/2}/F} \tag{6}$$

where C and r are material constants, F is the field strength and ϕ_0 is the work function as determined from the variation in emission with temperature. Experimental data have been shown to be in satisfactory agreement with this theoretically deduced relation.

Concluding Remarks

Obviously, in an article of this length it has been possible to present only some of the more important observations and conclusions that have been obtained from investigations in this field. No mention has been made of the relation between thermionic and photoelectric effects, and only a brief reference has been made to the phenomena of positive ion emission. For a more complete discussion of these topics as well as of those touched upon in the present summary, the reader may consult the following references:

1. O. W. Richardson, Thermionic Emission, Longmans, Green and Company, London (1916).

2. S. Dushman, Reviews of Modern Physics, Vol. 2, 381 (1930). A review of the subject up to that date.

3. W. S. Stiles, Department of Scientific and Industrial Research, Special Report No. 11, London, England, 1932. "A survey of existing knowledge (on thermionic emission) with particular reference to the filaments of radio valves.

4. K. T. Compton and I. Langmuir, Review of Modern Physics, 3, 191 (1931). A review of gas discharge phenomena in general, including some of the topics discussed by the writer.

No mention has been made of the numerous treatises in German, especially that by Schottky, but references to these are given in the publications mentioned.

Insulator Arcover in Air

Although much is yet unknown about the many factors concerned in insulator arcover, humidity tests presented here lead to a theory of arcover. The geometrical design of the insulator is shown to be a minor factor at power frequencies, but of importance for withstanding impulse voltages.

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In many respects, the old problem of insulator arcover is in the same state of solution after nearly 40 years as it was in the early days of high voltage apparatus construction, for satisfactory explanations of some of the observed phenomena still are lacking. In this paper it is shown from test results that atmospheric humidity affects the arcover strengths of insulating materials in a somewhat erratic manner and quite independently of whether the material is hygroscopic or "greasy." Other factors that have large influences are enumerated and explained, and insulators whose arcover strengths are independent of humidity are described. A theory of arcover is offered, and test data obtained with continuous and impulse voltages, as well as with alternating voltages, are presented. Laboratory tests of commercial insulators are analyzed and correlated with the fundamental properties of the insulations. Briefly, it is shown that:

1. Atmospheric humidity may reduce the arcover strength of a clean, smooth surface to $^1/_3$ of the breakdown strength of the parallel path in air. The remedy is to break up the smooth surface into several shorter lengths by means of ribs or flanges of the same insulating material. If the flanges are spaced uniformly and sufficiently close together, they may offset entirely the effect of the atmosphere.

2. Correction of test data to "standard conditions" by means of the air density δ, whether necessitated by pressure or temperature differences from standard, is likely to lead to error if a linear relation is assumed.

3. Dirt, salt, water, and other semiconducting coatings give a real significance to surface resistance, but the latter need be calculated only as a length divided by circumference, integrated over the entire surface, instead of in actual ohms which may vary over a wide range and not affect the arcover strength.

4. Commercial insulators of approximately 1-ft arcing length have a 60-cycle arcover voltage when clean and dry of somewhat more than $^1/_4$ the ideal puncture voltage of a 1-ft air gap between plate electrodes. Suspension insulators of 12-ft length tested horizontally by Angus[20] have an arcover strength of only $^1/_5$ of that for the ideal air gap. One may obtain the ideal value for air by extrapolating the upper curve of Fig. 3. If transmission line voltages are to be pushed to considerably higher magnitudes than at present, some advantage no doubt will have to be taken of the greater arcover strength obtained by providing a uniform field in the neighborhood of each insulator. Another improvement can be obtained by more

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closely spaced flanges, and the direct wetting by rain may need to be prevented.

5. Although impulse voltage searches out to a considerable extent certain weaknesses in insulator design, it is well to recognize that the numerical value usually exceeds the 60-cycle arcover voltage; hence, in the end, the latter may be the critical one.

6. Laboratory test reports should be more complete, including such essential information as the rating of the testing source and its impedance, and the protective resistance in series with the insulator under test. It is believed that many discrepancies will be explainable if this procedure is followed.

An Unexplained Phenomenon

As an example of one of the unexplained phenomena, 2 metal plates, Fig. 1a, approximately flat but with smoothly rounded edges, and supported parallel to each other 1 cm (0.394 in.) apart, can withstand an alternating or a continuous voltage having a maximum value of 30 kv before a spark will pass between the plates. (Crest values of alternating voltage will be used exclusively herein in order to facilitate comparison with continuous and impulse voltage tests.) A piece of insulation carefully shaped into the form of a right cylinder 1 cm long and placed between the plates, Fig. 1b, although theoretically having no disturbing influence on the electric field, will be found by test to have reduced the breakdown strength of the gap to perhaps 15 kv or less. A satisfactory reason for this behavior is not obvious, and in fact is not known.

Surface Effects

By means of the simple testing apparatus of Fig. 1 such uncertainties as nonuniform voltage distribution over the insulator surface, electric field distortion in the medium outside, corresponding field distortion inside the insulation material, and the influence of parasitic capacitance are eliminated.

Atmospheric humidity has become recognized as an important factor in the arcover strength of most insulation, but the exact degree of its influence is uncertain. Figure 2, curves A to G, gives results obtained by 2 different investigators[3,6] who used alternating voltages of power frequency. Space does not permit a full discussion of the advantages of plotting relative humidity as a coördinate in place of one or other of the absolute humidity scales. The chief reason for its use here is to avoid the discontinuity above 100 per cent humidity that is always bothersome with an absolute scale. A check of the values of Fig. 2 in the laboratory yields points well scattered over the area included between the 2 sets of curves, most points, however, lying in the lower part of the area. It was not possible to duplicate Ritz's curves A to C which are higher than those obtained by any other experimenter, and there is reason to believe that they are peculiar to his apparatus, which was mechanically the most perfect

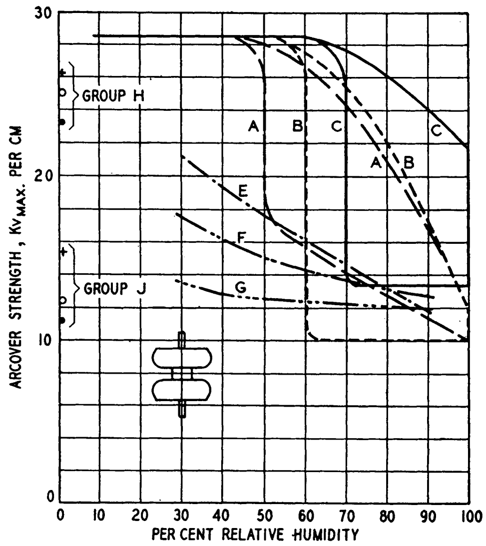

Fig. 2. Effect of relative humidity on arcover strength

Curve A. Paraffine right cylinder, Rogowski[2] electrodes, sparking distance 3.0 cm 50 cycles, series resistance 400,000 ohms, 45 to 20 deg C, 76 cm, absolute humidity constant at 1.8 cm mercury; from Ritz.[3] The uppermost horizontal line of curves A, B, and C corresponds to the strength of the air gap alone

Curve B. Glass right cylinder, conditions as for A; from Ritz

Curve C. Bakelite right cylinder, conditions as for A; from Ritz

Curve E. Paraffine right cylinder, flat electrodes with rounded edges; sparking distance 3.0 cm, 50 cycles, 20 deg C, 76 cm; from Schwaiger[6]

Curve F. Glass and unglazed porcelain right cylinders, conditions as for E; from Schwaiger

Curve G. Shellac right cylinder, conditions as for E; from Schwaiger

Points, Group H. Paraffine right cylinder, flat electrodes with curved edges of 20 cm radius; sparking distance 3.0 cm, 20 deg C, 76 cm. Upper point, surge voltage (wave form not given); middle point continuous; lower point 50 cycles; from Inge and Walther[11]

Points, Group J. Glass right cylinder, conditions as for H; from Inge and Walther

of all. A very elaborate test was made on heat-resistant glass in which the sample after first being baked in a vacuum at 300 deg C for 2 hours was next supplied with air at atmospheric pressure in the same apparatus. The air before being admitted was dried carefully by freezing at liquid air temperature. An arcover strength of this sample equal to the strength of the air gap alone was observed. This and a somewhat similar test made by Inge and Walther[11] seem to be the only results thus far obtained agreeing with Ritz's extraordinary observations, and even then his unusually high figures were not checked at humidities other than zero.

Such surface characteristics as roughness, oiliness and absorptiveness have no important influence on arcover strength. Tests show conflicting results, but these easily may be attributed to other effects. Rice[13] found that surface coatings of oil, grease, or varnish on insulation give rise to improved arcover strength, but there are too many other factors in-

3. For all numbered references see bibliography at end of paper.

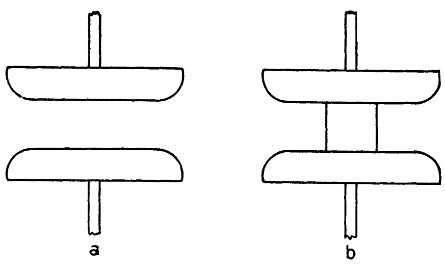

Fig. 1. Spark gap with plane parallel electrodes (a); and (b) same gap with insulation sample in place

volved in such experiments to lay much stress upon the results.

The terms "surface resistance" and "creepage distance" have been shown definitely to have no meaning in the "dry" arcover behavior of insulation, i. e., in the range of 0 to 100 per cent relative humidity, so long as no droplets of liquid appear on the surface of insulator or electrodes. The situation, however, is entirely different for wet, dirty, or salt-coated insulation according to Wood[1], who defines surface resistance as the integrated length-divided-by-circumference and proves it to be a practical measure of the arcover strength of complicated commercial insulators salt-coated. Tests in the high voltage laboratory of the California Institute of Technology on simple right cylinders coated with salt gave the same arcover potential per unit resistance as obtained by Wood.

Details of the Testing Gap and Testing Circuit

Electrodes of accurately flat form are unsuited to this type of arcover test because they produce an excessive stress in the air near their rounded edges. A much better contour has been suggested by Rogowski.[2] It is the same as an equipotential surface in the field between 2 thin flat sheet electrodes and was so chosen that the maximum stress in the air is nowhere appreciably greater than in the useful part of the gap. One such surface can be generated by rotating about the y axis the plane curve

$$x = 0.2385d \left[2.3026 \log \left\{ 4.83{,}5\left(\frac{y}{d} - \frac{1}{2} \right) \right\} - 2.4175 \left(\frac{y}{d} - \frac{1}{2} \right) + 8.71 \right]$$

where x and y are the ordinary variables and d is the desired length of spark gap in the same units. For other suitable equipotential curves the reader is referred to theoretical works on electrostatics. In order to complete the electrode its thickness should be made about $1.5d$, and a plane back may be used or the inside bored out to reduce the weight if of large size. It must be polished carefully and so maintained for all tests. The finished electrode resembles a door knob and may be used without great error for spark gaps from $^1/_2d$ to $2d$.

The mechanical fit between electrodes and insulation is of the utmost importance. Practically the whole range of observed arcover strengths, for a given relative humidity, Fig. 2, can be obtained by changes in the perfection of the fit between sample and electrodes, especially at the cathode. Ritz[3] secured test pieces made with optical precision and reports the best arcover strengths that have been observed below 70 per cent humidity, as shown by Fig. 2. Wax and oil as filters for the spaces left by poorly made ends of specimens are of little or no value because of their low dielectric constants.

Analogous to the Wagner[4] effect of protecting solid insulation from puncture by using high resistance electrodes is the insertion of resistance or reactance into the testing circuit to prevent arcover. Different experimenters use large, small, or medium capacity sources of voltage according to the available facilities in their respective laboratories. The results should not be expected to be comparable and can be compared legitimately only when all testing conditions are known, including impedance of the test circuit.

Geometrical Factors and Atmospheric Density

The free length has a strong influence on the arcover gradient. The upper curve of Fig. 3 shows how the breakdown strength of the spark gap alone varies

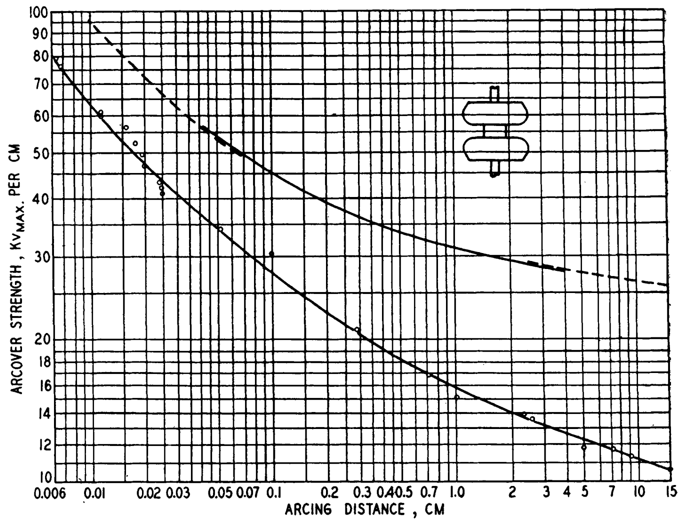

Fig. 3. Effect of sparking distance upon arcover strength

Lower Curve. Glass, "pyrex" and porcelain right cylinders between polished flat electrodes, relative humidity 60 per cent, temperature 20 deg C (approx.), barometer 76 cm, 50 cycles. Upper Curve. Air only, between polished flat electrodes. Left end from experiments of Liebig[5] with plane to sphere as electrodes (corrected for curvature of sphere). Middle from Ritz[3] 1932, Rogowski electrodes. Right end from Schumann;[7] flat electrodes with long radius edges

with the sparking distance. The lower curve shows the nice manner in which the arcover strength of a solid under constant atmospheric conditions parallels the curve for air alone.

The relative diameter of the specimen has no influence except that very slender fibers show somewhat higher arcover voltages than a larger cross section of the same material. Strips of paper tested in the long direction had arcover strengths practically equal to that of the gap alone.

Atmospheric pressure and temperature different from standard conditions usually are corrected for by the use of a relative air density factor δ which is $\frac{3.92b}{273 + t}$ where b is barometric pressure in centimeters of mercury and t is temperature in degrees Centigrade. It assumes linear variations of both effects. In Figs. 4a and 4b it is shown clearly that even for the breakdown strength of air alone the pressure effect is not linear and for arcovers it may be far from linear. Fig. 4c shows that the temperature effect curves bend the other way, hence a correction in which both temperature and pressure change δ in the same direction and by similar amounts is fairly accurate, but considerable error will be made under other circumstances.

A complete set of curves for correction to standard temperature and pressure would be quite laborious to make or use, and other influences of uncertain nature cause individual readings to vary from each other by margins large enough to discourage attempts at great precision in calculations. It is recommended, however, that arcover data not be corrected to standard conditions, but, instead, presented as obtained.

A Theory of Insulator Arcover

The surface of a solid object is not what the eye sees, but rather a molecular pattern against which gas molecules from the surrounding atmosphere are held in corresponding pattern. The succeeding layers in the direction away from the solid differ little by little until they merge with the atmosphere itself, but the lowermost layers of gas molecules are as dense as though at a pressure of several hundred atmospheres

Table I—Arcover Strength of 7.6-cm Bakelite Rod, 260 Threads Per Inch, With Varying Relative Humidity

Temperature 20–22 deg C, barometer 74 cm, protective resistance 2 megohms, flat electrodes with curved edges, 50 cycles, transformer impedance 10,000 ohms

Crest Voltage, Kv	Crest Gradient, Kv Per Cm	Per Cent Relative Humidity
*137	18.0	29
156	20.6	29
147	19.3	33
153	20.2	37
150	19.7	39
156	20.6	50
144	18.9	50
155	20.3	77
*123	16.1	89
150	19.7	95
160	21.1	95
161	21.2	95
157	20.7	95
** 80	10.5	100
†155	20.3	74
‡139	18.3	100
160	21.1	Air alone

* Arc struck along the sample.
** Distilled water sprayed on sample previous to applying voltage. Droplets on both sample and electrodes.
† After drying for 1 hour in humidity as shown.
‡ Sprayed again more lightly with distilled water.

Langmuir[8] and Davisson and Germer[9] have given a great deal of information regarding such adsorbed layers of gas molecules. Most significant for present purposes is that a "clean" surface of glass in contact with the ordinary atmosphere holds to itself 100 times as many water as nitrogen molecules.

Glass is soluble in water, especially in the presence of carbon dioxide. Here, then, is the source of an electrolyte covering the surface of the glass insulator. This is confirmed by an experiment in which a glass specimen was washed thoroughly by rubbing with water and a mildly abrasive soap (such as mechanics use to clean the hands), after which it was dried in paper towels and not touched by the fingers. For 3 days it withstood an atmosphere of 85 to 90 per cent humidity without appreciable reduction in arcover strength; but finally the attack of the atmosphere aided by the heat of the arcs which occurred during the tests brought about the usual surface conditions and the arcover strength was reduced to that normally observed. A freshly drawn fiber of glass did not come to equilibrium with the atmosphere for about 24 hours.

The physical picture, then, of insulator arcover is that of a surface thinly covered by electrolyte. The applied voltage drives a current through the conducting medium, causes local heating, violent evaporation in patches and consequent alternate areas of high and low resistance. Arcs begin in the high resistance areas long before an arc would form simultaneously over the entire surface. When once an arc has formed, complete breakdown soon follows. Impulse arcover voltages are always higher than continuous or 60-cycle alternating voltages, and it may be assumed that the time-consuming nature of evaporation is an explanation of this.

That insulations other than glass behave similarly makes one search for another source of surface electrolyte. Minute dust particles, carbon dioxide from the air, and foreign substances not previously removed from the surface of the specimen are no doubt sufficient.

A bad mechanical fit between specimen and electrodes, especially at the cathode where spark formation always begins (according to Dunnington's[12] visual tests), affords air space where corona or a spark is sure to form at a voltage lower than the full strength of the test gap. Even an incipient spark, caused by short-circuiting part of the useful length of a specimen, can precipitate a complete arcover at subnormal voltage.

Table II—Arcover Strength of 9.1-cm "Pyrex" Rod, 260 Threads Per Inch, With Varying Relative Humidity

Temperature 16–19 deg C, barometer 75 cm, protective resistance 90,000 ohms, flat electrodes with curved edges, 50 cycles, transformer impedance 10,000 ohms

Crest Voltage, Kv	Crest Gradient, Kv Per Cm	Per Cent Relative Humidity
189	20.7	61
190	20.8	64
197	21.6	68
175	19.3	68
185	20.3	84
191	21.0	95
*123	13.5	95
191	21.0	Air alone

* Arc struck along the sample.

An Application of Fundamentals

That the shorter is the striking distance, the greater is the unit strength of an insulator surface is shown by

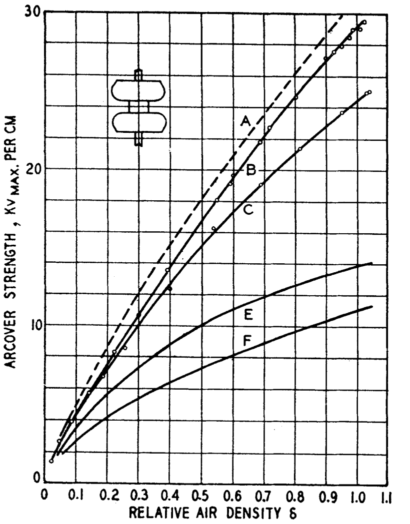

Fig. 4a. Effect of relative air density upon arcover strength

Constant temperature 20 deg C; 50 cycles
Curve A. Air only, sparking distance 1.0 cm, flat electrodes with curved edges of 20 cm radius from Inge and Walther[11]
Curve B. Pyrex right cylinder, sparking distance 0.73 cm, flat electrodes with rounded edges, relative humidity zero (approx.), series resistance 90,000 ohms, including transformer
Curve C. Glass right cylinder, sparking distance 1.04 cm, flat electrodes with rounded edges, relative humidity zero (approx.), series resistance as for B
Curve E. Glass right cylinder, sparking distance 1.0 cm, flat electrodes with curved edges of 20 cm radius, relative humidity zero (approx.), from Inge and Walther
Curve F. Glass right cylinder, sparking distance 3.0 cm, flat electrodes with curved edges of 20 cm radius, relative humidity zero (approx.), from Inge and Walther

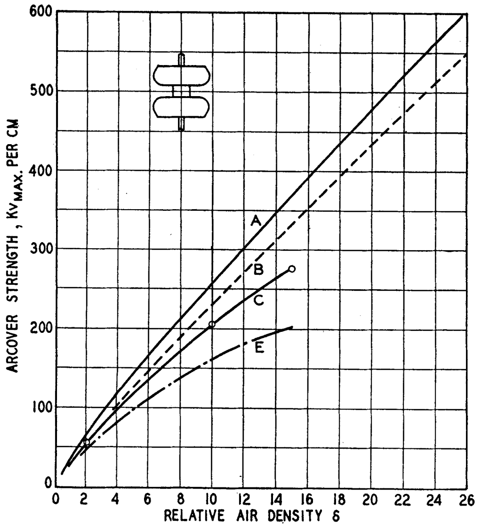

Fig. 4b. Effect of relative air density upon arcover strength

Constant temperature 20 deg C; 50 cycles
Curve A. Air only, sparking distance 0.3 cm, Rogowski electrodes; from Reher[10]
Curve B. Air only, sparking distance 1.0 cm, Rogowski electrodes; from Reher
Curve C. Hard rubber right cylinder, sparking distance 0.3 cm, relative humidity zero (approx.), Rogowski electrodes; from Reher
Curve E. Glass right cylinder, sparking distance 1.0 cm, relative humidity zero (approx.), values extrapolated from the works of several investigators

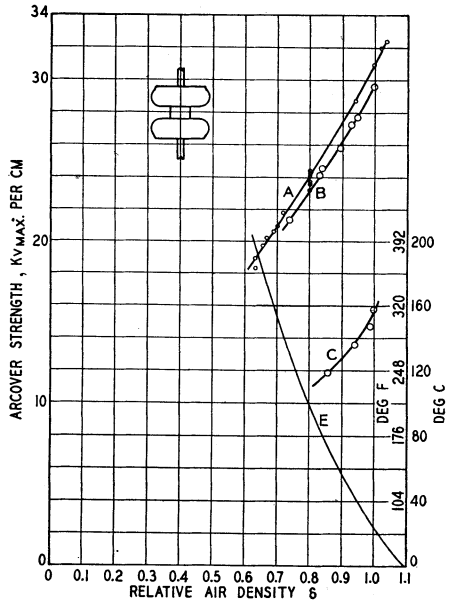

Fig. 4c. Temperature effect of relative air density upon arcover strength

Constant barometer 76.0 cm, 50 cycles
Curve A. Air only, sparking distance 1.0 cm, Rogowski electrodes, series resistance 120,000 ohms
Curve B. Pyrex right cylinder, sparking distance 0.73 cm, flat electrodes with rounded edges, relative humidity zero (approx.), series resistance 90,000 ohms
Curve C. Pyrex right cylinder, sparking distance 2.62 cm, flat electrodes with rounded edges, relative humidity 40 per cent
Curve E. Temperature deg C against relative air density, for convenience

Fig. 3. Rice[13] made use of this fact by stacking alternate glass and metal disks, the latter larger in diameter, forming several high strength samples in series, with electrodes between. He soon discovered, however, that alternate glass disks are better. There were 2 defects in his model. The glass disks were not flat enough to fit together well and they were too thick ($^1/_{16}$ in.). Tables I and II give test results for a bakelite and a "pyrex" rod, respectively, each having cut on its surface a screw of 260 threads per inch (102 per centimeter) for the entire length. Both ends carefully were fitted to the electrodes. The arcover potential per unit length of each is practically independent of humidity, showing the effect of flanges breaking up the surface into short lengths. Flanges provided on commercial insulators have a similar function: When the insulator is clean and dry they break up its length into many shorter insulator surfaces in series, the flanges themselves acting as new electrodes. The effect of flanges is quite different when the insulators are wet or dirty: They then serve to increase the surface resistance as previously described under "surface effects"; thus they have a double duty.

It is now easy to set up a rule for the best spacing of flanges. First determine the total length of the surface between the nearest electrodes. Find the arcover kilovolts per centimeter from Fig. 3 for the air gap alone of that length; multiply the value thus found by 3 and find on the same curve the corresponding length. It is the best spacing of flanges. As an example, suppose the distance between electrodes is 6 in. (15 cm). The corresponding unit strength of the air gap is 26 kv per centimeter, and $3 \times 26 = 78$. The length of air gap having 78 kv per centimeter breakdown strength is 0.015 cm or 0.006 in. It would be difficult to provide ribs or flanges at such minute spacing; hence it must not be expected that commercial insulators will have the same arcover strength as an equal length of air gap. The ratio 3 as just used is obtained from Fig. 2 in which the arcover strength for 100 per cent humidity is about $^1/_3$ that for the air gap alone.

Brasch and Lange[14] used the principle of uniformly spaced flanges in the construction of a 2.4-megavolt vacuum tube. Ritz[3] found that laminated paper rods in which the sheets were perpendicular to the axes had arcover strengths equal to the air gaps even in an atmosphere of 100 per cent humidity. Cotton tapes and string show similar properties.

A much more easily constructed test arrangement than those previously described and one which has many of the properties of a commercial pin or even suspension insulator was reported by Littleton and Shaver.[16] It consists of a rod of the test insulation

Table III—Influence of the Intervening Insulation Upon the Dry Arcover Voltage of 2 Similar Shield Rings

Diameter of rim material $2^{1}/_{2}$ in., outside diameter of entire ring 22 in., depth of ring fastening below rim $6^{1}/_{2}$ in., protective resistance zero, transformer 1,000 kva 1,000 kv, 50 cycles, 16 per cent impedance

Minimum Sparking Distance, Cm	Crest Voltage, Kv	Crest Gradient, Kv Per Cm	Per Cent Relative Humidity	Temperature, Deg C	Barometer, Cm Hg	Nature of Insulation
71	515	7.25	77	23	74.5	$3^{1}/_{2}$-in. glazed porcelain tube 105 cm long
102	710	7.0	77	23	74.5	Same tube
100	720	7.2	77	23	74.5	3 $^{1}/_{4}$-in. cotton ropes, each 130 cm long
100	720	7.2	77	22	74.5	8 10-in. standard suspension units spaced $4^{3}/_{4}$ in.
100	720	7.2	72	22	74.0	*7 high strength fog type units spaced $6^{1}/_{2}$ in.

* Data from tests by R. J. C. Wood, not published.

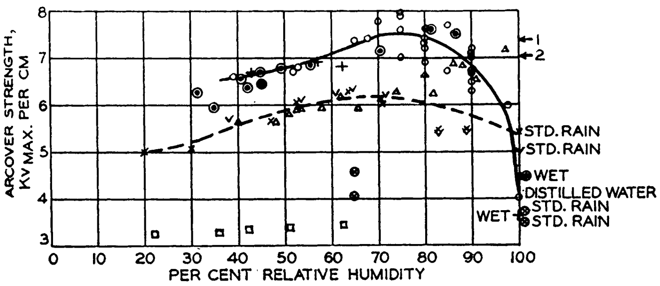

Fig. 5. Effect of atmospheric humidity upon the arcover strength of 3 types of commercial insulator; also rods with wire electrodes

o Glass rod $1^{1}/_{16}$ in. diameter; No. 8 AWG copper wire electrodes spaced 11.6 cm, 19 to 20 deg C, 74.5 cm mercury, 50 cycles

△ Pyrex rod 0.90 in. diameter; No. 6 AWG copper wire electrodes, spaced 35.5 cm, 21.7 to 30.2 deg C, 76.0 cm, 60 cycles; from Littleton and Shaver[16]

× Suspension string of 3 10-in. units, dry striking distance 49 cm, 25 deg C, 76.0 cm, 60 cycles; from Peek[15]

□ Apparatus bushing (not oil filled), bare conductor in place; striking distance 80 cm, wet or dry, 25 deg C, 76.0 cm, 60 cycles; from Frey and Hawley[17]

+ Apparatus bushing, as above; striking distance 12.7 cm; from Frey and Hawley

v Suspension string of 3 10-in. units; dry striking distance 49 cm; 30 to 31.5 deg C, 76.0 cm, 60 cycles; from Lloyd[18]

←1 Suspension string of 3 10-in. units spaced $5^{3}/_{4}$ in.; dry striking distance 49 cm, surge voltage of 2-μ sec front; from Torok and Archibald.[19] Same value wet or dry

←2 Suspension string of 18 10-in. units spaced $5^{3}/_{4}$ in.; dry striking distance 265 cm, surge voltage of 2-μ sec front; from Torok and Archibald. Same value wet or dry

◉ Pyrex pin type insulator; striking distance 13.2 cm, 10.6 to 26.8 deg C, 76.0 cm, 60 cycles; from Littleton and Shaver

⊗ Upper points string of 10-in. units (vertical) dry; arcing distance 100 in., 60 cycles

⊗ Lower points outdoor pedestal type insulator (vertical) dry; arcing distance 100 in., 60 cycles; from discussion by J. E. Clem of paper by Frey and Hawley[17]

near each end of which is wrapped snugly a piece of heavy copper wire.

The curve of arcover strength against relative humidity for this simple rod is identical in shape with that of the pin insulator or suspension string, and, perhaps even more important, the actual arcover potentials per unit length of arcing distance resemble each other very closely as shown in Fig. 5.

Commercial Insulators

Technical literature seems to abound in reports of insulator tests that attempt to prove the differences between this and that shape, size or arrangement. The striking fact, however, is their similarity. Figure 5 is a collection of tests from many sources, assembled to show this similarity. The solid curve was drawn for a Littleton and Shaver type glass rod specimen 11.6 cm long, the dashed curve for a suspension string of 3 10-in. units. Other points have been inserted to show the remarkable agreement in arcover strength among commercial insulators of totally different designs. *The spread of the points in any individual test is practically equal to the spread of points from radically different classes of structures.* The only offenders are the apparatus bushing, which, because of its internal electrode, behaves unlike any other insulator used in electrical engineering, and the rather long (100 in.) pedestal and insulator string which are actually out of the range of length represented by the other tests. Curves such as those in Fig. 5 can be drawn for insulators having approximately 100-in. arcing distance. They will show lower arcover strengths than the 12-in. insulators. Thus 2 prominent fundamental characteristics have been brought out. First, in dry arcover, different shaped insulators, exclusive of apparatus bushing, having the same arcing distance have roughly the same arcover strength, which is here expressed in kilovolts per centimeter. Second, the arcover potential per centimeter diminishes when the length is increased just as it does for the right cylinders in uniform fields, Fig. 3. Table III is given in order to show that even more drastic changes in the nature and form of the insulation do not influence the arcover strength in the dry test at 60 cycles when the electrodes have the form of shield rings. Impulse tests, on the contrary, are influenced strongly by the geometrical details of the insulator.

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A Glow Discharge Anemometer

A glow discharge at atmospheric pressure is responsive to air velocity, and may be used as an anemometer. The properties of such a glow are discussed in this paper, and data relating to glow current, voltage, glow length, and air velocity are presented. It is also shown that the glow discharge responds to rapid fluctuations in air velocity and is therefore a practical device for investigating turbulence. A comparison of such an anemometer with the previously used hot wire method is given.

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RECENT aerodynamical research of both theoretical and experimental nature has indicated the important influence which air turbulence has on wind tunnel measurements. Experimental quantities, the lift and drag coefficients, are materially affected by the existence of small fluctuations superposed on the measured stream velocity. Moreover, these fluctuations in velocity, constituting turbulence, are characteristically of relatively high frequency and random nature, so that their presence is not indicated by air speed meters, manometers, or other velocity measuring devices involving inertia. Accordingly a need exists for methods of studying such turbulence both quantitatively and qualitatively.

Numerous schemes for meeting this need have been proposed and investigated heretofore, only one of which, the hot wire anemometer, satisfies at all well the aerodynamical requirements. This device, ostensibly simple and relatively satisfactory, consists of a fine wire heated electrically by current flow and subjected to the variable cooling induced by the velocity fluctuations in the moving air stream. The corresponding variations in voltage drop of the wire are amplified to measurable proportions for oscillographic study or direct meter indication.

Difficulties Inherent in Hot Wire Anemometer Scheme

Inherent in this scheme are 2 fundamental difficulties, compensation and calibration, both of which are surmountable but not without the introduction of some ambiguity into the results. Since ordinary turbulence has a frequency spectrum much like that of acoustic noise, compensation is essential because the hot wire response is much greater for low frequency velocity fluctuations than for those of high frequency. In order to obtain something approximating a faithful reproduction of turbulence a distorting circuit must be employed in the amplifying equipment, the characteristics of which are dictated by the various factors contributing to the "lag" of the wire. The lag characteristics of the wire are, in turn, determined from a theoretical analysis necessarily involving assumptions and approximations. Such procedure is a rational one and necessary; but, it is unfortunate that no standard turbulence exists nor has any velocity fluctuation thus far been devised whose characteristics, in magnitude and quality, are known without serious ambiguity to serve as an over-all check on the fidelity of the hot wire apparatus except for very low frequencies. Moreover, the fairly obvious test which may be made of compensation by passing through the wire a heat-

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1. For all numbered references see list at end of paper.